Marine Pollution Bulletin 97 (2015) 262–272

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Ecologically based targets for bioavailable (reactive) nitrogen discharge from the drainage basins of the Wet Tropics region, Great Barrier Reef

Scott A. Wooldridge [a,b,*], Jon E. Brodie [b], Frederieke J. Kroon [a], Ryan D.R. Turner [c]

[a] *Australian Institute of Marine Science, PMB 3, Townsville MC, QLD 4810, Australia*
[b] *Centre for Tropical Water and Aquatic Ecosystem Research, JCU Townsville, QLD 4811, Australia*
[c] *Department of Science, Information, Technology and Innovation, Queensland Government, Brisbane, QLD 4001, Australia*

ARTICLE INFO

Article history:
Received 10 November 2014
Revised 2 June 2015
Accepted 3 June 2015
Available online 10 June 2015

Keywords:
Water quality
Coral bleaching
Crown-of-thorns starfish
Coral health
Nutrient enrichment
Resilience

ABSTRACT

A modelling framework is developed for the Wet Tropics region of the Great Barrier Reef that links a quantitative river discharge parameter (viz. dissolved inorganic nitrogen concentration, DIN) with an eutrophication indicator within the marine environment (viz. chlorophyll-*a* concentration, chl-*a*). The model predicts catchment-specific levels of reduction (%) in end-of-river DIN concentrations (as a proxy for total potentially reactive nitrogen, PRN) needed to ensure compliance with chl-*a* 'trigger' guidelines for the ecologically distinct, but PRN-related issues of crown-of-thorns starfish (COTS) outbreaks, reef biodiversity loss, and thermal bleaching sensitivity. The results indicate that even for river basins dominated by agricultural land uses, quite modest reductions in end-of-river PRN concentrations (~20–40%) may assist in mitigating the risk of primary COTS outbreaks from the mid-shelf reefs of the Wet Tropics. However, more significant reductions (~60–80%) are required to halt and reverse declines in reef biodiversity, and loss of thermal bleaching resistance.

1. Introduction

The Great Barrier Reef World Heritage Area (GBRWHA) is located along the north-eastern Australian coast and consists of a diverse range of ecosystems including coral reefs, seagrass meadows, mangrove forests and open water communities. On its western boundary, 35 basins discharge into the GBRWHA over ~2000 km of Queensland coastline (Fig. 1). Loads of pollutants discharging from these basins have increased greatly with the development of the river catchments for agriculture over the past 150 years (Furnas, 2003; Kroon et al., 2012; Waters et al., 2014). Pollutant loads have increased by 3–5 times for suspended sediment (Kroon et al., 2012), 2–6 times for total nitrogen (TN) (Kroon et al., 2012; Waters et al., 2014), and 2–3 times for dissolved inorganic nitrogen (DIN) (Mitchell et al., 2009; Kroon et al., 2012; Waters et al., 2014). For the Wet Tropics rivers specifically, the most recent estimates of the changed loads based on Sources Catchments modelling (Carroll et al., 2012) validated with monitoring data (Hateley et al., 2014; Waters et al., 2014) derived from the GBR Loads Monitoring Program (Turner et al., 2012, 2013; Wallace et al., 2013) suggest increase factors of 2.5 for PN, 2.1 for DON, and 1.8 for DIN with the increase factors for individual Wet Tropics Rivers as detailed in Table 1. Marine waters of the Wet Tropics also receive substantial nitrogen inputs from the Burdekin River as the prevailing inshore currents carry discharged water and nutrients to the north of the Burdekin mouth (Bainbridge et al., 2012; Fig. 1)

Emerging evidence associates excess nutrient pollutant export from the Wet Tropics and Burdekin Rivers with: (i) reef degradation and overall reduced coral biodiversity between Townsville and Cooktown, e.g. a reduction in species richness of 40 species, compared with the expected value, is evident in the area adjacent to the Tully River (Fabricius et al., 2005; DeVantier et al., 2006), (ii) enhanced vulnerability of reef corals to thermal bleaching stress, e.g. a 2–3-fold higher bleaching risk per unit thermal anomaly in the coastal reef areas of the Wet Tropics (Wooldridge, 2009), and (iii) reef damage from coral-eating crown-of-thorns starfish (COTS, *Acanthaster planci*) outbreaks (Brodie et al., 2005; Fabricius et al., 2010). At a global scale, the effects of excess nutrients on coral reef ecosystems, is also well recognised in analogous ways to the GBR (reviewed by D'Angelo and Wiedenmann, 2014).

In response to these, and other identified threats posed to the GBRWHA ecosystems from land-based pollution (Brodie et al., 2001), a joint Australian and Queensland State governments Reef Water Quality Protection Plan (Reef Plan) was developed in 2003 (with further revisions in 2009 and 2013) (Queensland

---

* Corresponding author at: Australian Institute of Marine Science, PMB 3, Townsville MC, QLD 4810, Australia.

E-mail address: s.wooldridge@aims.gov.au (S.A. Wooldridge).

http://dx.doi.org/10.1016/j.marpolbul.2015.06.007
0025-326X/© 2015 Elsevier Ltd. All rights reserved.

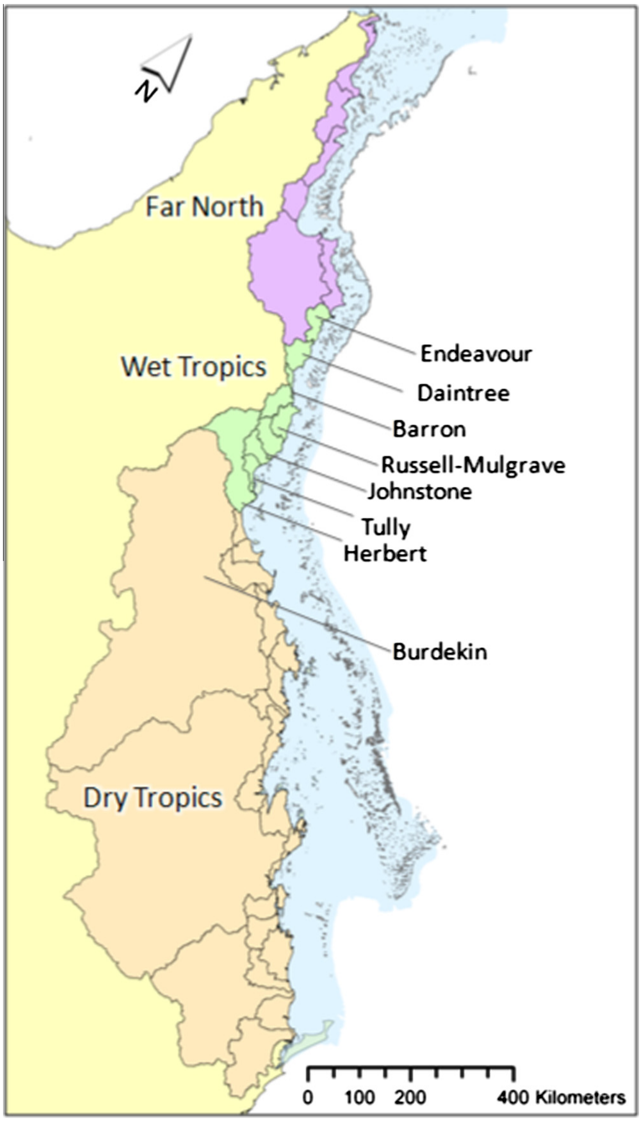

Fig. 1. The Great Barrier Reef and its catchments. Wet Tropics catchments are represented in green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Government, 2009). The overall objective of Reef Plan is "To ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the GBR" (Queensland Government, 2009). The most recent (2013) amendments to Reef Plan set a target of at least a 50% reduction in anthropogenic end-of-catchment DIN loads in priority areas and a 20% reduction in PN to be achieved by 2018 (Queensland Government, 2013). Other pollutants including phosphorus, suspended sediments and certain pesticides also have reduction targets to be achieved by 2018. While aspirational, these targets are based largely on what is thought to be feasible through improved practices in agricultural land uses in the Great Barrier Reef Catchment (GBRC), rather than based on desired ecological states of the GBRWHA (Brodie et al., 2012a; Kroon, 2012). There is thus no guarantee that the Reef Plan targets will deliver its overall objective by 2020 (Kroon, 2012).

Table 1
Estimated factor increases for DIN and PN loads from Wet Tropics Basins based on a comparison of estimated pre-European loads and a modern baseline (2009) loads estimate. *Source:* Hateley et al. (2014) and Waters et al. (2014).

River basin	Increase factor DIN	Increase factor PN
Daintree	1.2	1.4
Mossman	1.9	1.7
Barron	1.9	2.7
Russell–Mulgrave	1.6	2.0
Johnstone	2.7	3.4
Tully	2.0	2.0
Murray	1.7	1.6
Herbert	1.5	3.3

Recently, marine ecosystem health guidelines have been developed for water quality stressors (De'ath and Fabricius, 2008) that are "intended to protect marine ecosystems of the Great Barrier Reef from exposure to particular contaminants" (Great Barrier Reef Marine Park Authority, 2010). The guidelines are considered trigger values that, if exceeded, identify the need for management responses. For bioavailable (i.e. reactive) nutrients, the ecosystem health indicator is reported in terms of the resultant 'bloom' concentration of *in situ* phytoplankton (see e.g., Schaffelke et al., 2012). In warm tropical reef waters, measures of phytoplankton biomass usually provide a better indicator of the nutrient status than actual measured nutrient concentrations, since fast growing phytoplankton populations quickly respond to, and subsequently deplete, all available stocks of bioavailable nutrients; resulting in localised phytoplankton blooms (Edwards et al., 2003; Furnas et al., 2005). Concentrations of the photosynthetic pigment, chlorophyll-*a* (chl-*a*), is the most commonly used measure of phytoplankton biomass, and has been adopted as the ecosystem indicator for eutrophication impacts within GBR coastal reef waters (De'ath and Fabricius, 2008; Great Barrier Reef Marine Park Authority, 2010; Brodie et al., 2011).

The challenge for reef managers is to identify ecologically based end-of-river water quality targets that ensure GBR water quality 'health' guidelines are continuously achieved at reefs located some distance from the river mouths. In this way, the sufficiency (or not) of the current Reef Plan targets can be assessed in terms of its overall objective. Though conceptually self-evident, providing a rational framework upon which to derive ecologically based targets is a notoriously difficult process, in part due to the lack of appropriate tools with which to link end-of-catchment water quality parameters and quantitative health indicators in the marine environment. Multiple forms of potentially reactive nitrogen (PRN) are also exported from the agricultural-dominated Wet Tropics Rivers and the Burdekin River (see below). These different forms of bioavailable nitrogen are strongly correlated (Lewis et al., 2014b), making it difficult to isolate specific impacts in the marine environment.

In this paper, we utilise the decision support tool 'ChloroSim' (Wooldridge et al., 2006) to establish a quantitative relationship between the DIN-component of nitrogen discharge in event flows and the resultant chl-*a* concentration in the marine environment. This relationship has been confirmed for the Wet Tropics region of the GBR, where observed summer chl-*a* concentrations in the inner-shelf areas increase significantly with the export of elevated DIN from the adjacent river catchments (Wooldridge et al., 2006). The ChloroSim model has previously been implemented to investigate the downstream effects of riverine DIN reductions, relative to present day, on the size and intensity of the enriching footprint of flood plumes within the GBR lagoon (Wooldridge et al., 2006; Brodie et al., 2009). In this paper, we reverse-engineer the ChloroSim model and calculate the catchment-specific (%) level of reduction in end-of-river DIN concentrations in the Wet Tropics (and Burdekin) needed to ensure compliance with the relevant chl-*a* guidelines for: (i) COTS outbreaks, (ii) reef health and biodiversity, and (iii) thermal bleaching sensitivity. We extrapolate the DIN result to PRN, which is the actual form of nitrogen load that has to be reduced. We discuss the feasibility and economic